

Present status of GRACE/SUSY

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1. Introduction
2. Tree level system
3. 1-loop level system
4. Outlook

LoopFest II

*Precision Measurements and Radiative Corrections at a Future Linear Collider :
SUSY, QCD, New Physics*

Brookhaven National Laboratory , Upton, NY

May 15, 2003

1. Introduction

Automatic calculation of amplitudes

-> important @ HE colliders

LHC,

TESLA, NLC, CLIC,

GLC (Global Linear Collider)

* many body final states

* possible many new particles

GRACE (Minami-Tateya)

CompHEP (Moscow)

hep-ph/0205020 , hep-ph/0111291 , hep-ph/0101232

Belanger et al. MicroOmega, hep-ph/0210327

Feyn series (Germany)

Hahn, Comput.Phys.Commun. 140 (2001) 418,143(2002) 54

MADGRAPH/MADEVENT (US)

Maltoni and Stelzer, JHEP 0302:027,2003

GRACE/SUSY

based on GRACE/SM

"IMPLEMENTATION OF THE NONLINEAR GAUGE INTO GRACE"

G. Belanger, et al. **hep-ph/9907406**

% tree level <- released already

"GRACE/SUSY AUTOMATIC GENERATION OF TREE AMPLITUDES
IN THE MINIMAL SUPERSYMMETRIC STANDARD MODEL"

KEK-CP-129, Aug 2002, **hep-ph/0208036**
Comput.Phys.Commun. 153 (2003) 106

<http://minami-home.kek.jp/>

% 1-loop level <- under checking!

2. Tree level system

MSSM

particle	variable name
photon	photon
$W^+(W^-)$	W-plus (W-minus)
Z	Z
gluon	gluon
$\nu_e(\bar{\nu}_e)$	nu-e (nu-e-bar)
$e^-(e^+)$	electron (positron)
$\nu_\mu(\bar{\nu}_\mu)$	nu-mu (nu-mu-bar)
$\mu^-(\mu^+)$	muon (anti-muon)
$\nu_\tau(\bar{\nu}_\tau)$	nu-tau (nu-tau-bar)
$\tau^-(\tau^+)$	tau (anti-tau)
$u(\bar{u})$	u (u-bar)
$d(\bar{d})$	d (d-bar)
$c(\bar{c})$	c (c-bar)
$s(\bar{s})$	s (s-bar)
$t(\bar{t})$	t (t-bar)
$b(\bar{b})$	b (b-bar)
h^0	Higgs1
H^0	Higgs2
A^0	Higgs3
$H^+(H^-)$	Higgs-plus (Higgs-minus)

particle	variable name
$\tilde{\chi}_1^+(\tilde{\chi}_1^-)$	chargino1 (anti-chargino1)
$\tilde{\chi}_2^+(\tilde{\chi}_2^-)$	chargino2 (anti-chargino2)
$\tilde{\chi}_1^0$	neutralino1
$\tilde{\chi}_2^0$	neutralino2
$\tilde{\chi}_3^0$	neutralino3
$\tilde{\chi}_4^0$	neutralino4
$\tilde{\nu}_e(\bar{\tilde{\nu}}_e)$	snu-e (anti-snu-e)
$\tilde{\nu}_\mu(\bar{\tilde{\nu}}_\mu)$	snu-mu (anti-snu-mu)
$\tilde{\nu}_\tau(\bar{\tilde{\nu}}_\tau)$	snu-tau (anti-snu-tau)
$\tilde{e}_1^-(\tilde{e}_1^+)$	selectron1 (anti-selectron1)
$\tilde{e}_2^-(\tilde{e}_2^+)$	selectron2 (anti-selectron2)
$\tilde{\mu}_1^-(\tilde{\mu}_1^+)$	smuon1 (anti-smuon1)
$\tilde{\mu}_2^-(\tilde{\mu}_2^+)$	smuon2 (anti-smuon2)
$\tilde{\tau}_1^-(\tilde{\tau}_1^+)$	stau1 (anti-stau1)
$\tilde{\tau}_2^-(\tilde{\tau}_2^+)$	stau2 (anti-stau2)
$\tilde{u}_1(\bar{\tilde{u}}_1)$	su1 (anti-su1)
$\tilde{u}_2(\bar{\tilde{u}}_2)$	su2 (anti-su2)
$\tilde{d}_1(\bar{\tilde{d}}_1)$	sd1 (anti-sd1)
$\tilde{d}_2(\bar{\tilde{d}}_2)$	sd2 (anti-sd2)
$\tilde{c}_1(\bar{\tilde{c}}_1)$	sc1 (anti-sc1)
$\tilde{c}_2(\bar{\tilde{c}}_2)$	sc2 (anti-sc2)
$\tilde{s}_1(\bar{\tilde{s}}_1)$	ss1 (anti-ss1)
$\tilde{s}_2(\bar{\tilde{s}}_2)$	ss2 (anti-ss2)
$\tilde{t}_1(\bar{\tilde{t}}_1)$	st1 (anti-st1)
$\tilde{t}_2(\bar{\tilde{t}}_2)$	st2 (anti-st2)
$\tilde{b}_1(\bar{\tilde{b}}_1)$	sb1 (anti-sb1)
$\tilde{b}_2(\bar{\tilde{b}}_2)$	sb2 (anti-sb2)

M. Kuroda, Complete Lagrangian of MSSM
 hep-ph/9902340

Input parameters

[Higgs & Gauginos](#)

$$\alpha_e, \alpha_s, M_W, M_Z, \tan \beta, M_{A^0}, \mu, M_1, M_2, M_3.$$

[Sfermions](#)

sfermion masses	$m_{\tilde{u}_i}, m_{\tilde{c}_i}, m_{\tilde{t}_i}$	amsu(1,i), amsu(2,i), amsu(3,i)	*
	$m_{\tilde{d}_i}, m_{\tilde{s}_i}, m_{\tilde{b}_i}$	amsd(1,i), amsd(2,i), amsd(3,i)	*
	$m_{\tilde{\nu}_e}, m_{\tilde{\nu}_\mu}, m_{\tilde{\nu}_\tau}$	amsn(1), amsn(2), amsn(3)	*
	$m_{\tilde{e}_i}, m_{\tilde{\mu}_i}, m_{\tilde{\tau}_i}$	amsl(1,i), amsl(2,i), amsl(3,i)	*
sfermion widths	$\Gamma_{\tilde{u}_i}, \Gamma_{\tilde{c}_i}, \Gamma_{\tilde{t}_i}$	agsu(1,i), agsu(2,i), agsu(3,i)	*
	$\Gamma_{\tilde{d}_i}, \Gamma_{\tilde{s}_i}, \Gamma_{\tilde{b}_i}$	agsd(1,i), agsd(2,i), agsd(3,i)	*
	$\Gamma_{\tilde{\nu}_e}, \Gamma_{\tilde{\nu}_\mu}, \Gamma_{\tilde{\nu}_\tau}$	agsn(1), agsn(2), agsn(3)	*
	$\Gamma_{\tilde{e}_i}, \Gamma_{\tilde{\mu}_i}, \Gamma_{\tilde{\tau}_i}$	agsl(1,i), agsl(2,i), agsl(3,i)	*
SUSY-breaking parameters	$m_u A_u, m_c A_c, m_t A_t$	xauq(1), xauq(2), xauq(3)	
	$m_d A_d, m_s A_s, m_b A_b$	xadq(1), xadq(2), xadq(3)	
	$m_e A_e, m_\mu A_\mu, m_\tau A_\tau$	xalp(1), xalp(2), xalp(3)	
sfermion mixing	$\sin \theta_{\tilde{u}}, \sin \theta_{\tilde{c}}, \text{angles } \sin \theta_{\tilde{t}}$	shuq(1), shuq(2), shuq(3)	*
	$\cos \theta_{\tilde{u}}, \cos \theta_{\tilde{c}}, \cos \theta_{\tilde{t}}$	chuq(1), chuq(2), chuq(3)	*
	$\sin \theta_{\tilde{d}}, \sin \theta_{\tilde{s}}, \sin \theta_{\tilde{b}}$	shdq(1), shdq(2), shdq(3)	*
	$\cos \theta_{\tilde{d}}, \cos \theta_{\tilde{s}}, \cos \theta_{\tilde{b}}$	chdq(1), chdq(2), chdq(3)	*
	$\sin \theta_{\tilde{e}}, \sin \theta_{\tilde{\mu}}, \sin \theta_{\tilde{\tau}}$	shlp(1), shlp(2), shlp(3)	*
	$\cos \theta_{\tilde{e}}, \cos \theta_{\tilde{\mu}}, \cos \theta_{\tilde{\tau}}$	chlp(1), chlp(2), chlp(3)	*

How to use

$$e^- e^+ \rightarrow \tilde{\chi}_1^+ \tilde{\chi}_1^0$$

```

Model="mssm.mdl";
Process;
ELWK=3;
QCD=0;
  Initial={electron,positron};
  Final  ={photon,chargino1,anti-chargino1};
Kinem="2302";
Pend;

```

code number	contents
1201	1-body \rightarrow 2 body decay
1301	1-body \rightarrow 3 body decay Sequential decay $1 \rightarrow 2 + (3 + 4) \rightarrow 2 + 3 + 4$ can be treated.
2201	2-body \rightarrow 2 body in CM frame t - and u -channel singularities can be treated.
2301	2-body \rightarrow 3 body in CM frame , Sequential decay type $1 + 2 \rightarrow 3 + (4 + 5) \rightarrow 3 + 4 + 5$. Resonance on particles 4 and 5 can be treated.
2302	2-body \rightarrow 3 body in CM frame , Radiative processes $1 + 2 \rightarrow 3(\gamma) + 4 + 5$, both initial and final radiation can be treated.
2303	2-body \rightarrow 3 body in CM frame , Double-radiative processes $1 + 2 \rightarrow 3(\gamma) + 4(\gamma) + 5$
2304	2-body \rightarrow 3 body in CM frame , Three photon processes $1 + 2 \rightarrow 3(\gamma) + 4(\gamma) + 5(\gamma)$
2401	2-body \rightarrow 4 body in CM frame, a pair of sequential decay type $1 + 2 \rightarrow (3 + 4) + (5 + 6) \rightarrow 3 + 4 + 5 + 6$ t -channel singularity can be treated.
2402	2-body \rightarrow 4 body in CM frame, 'fusion' type $1 + 2 \rightarrow (3 + A) + (4 + B); A + B \rightarrow 5 + 6$

Table C.2 Kinematics library prepared in GRACE/SUSY system.

gracefig

Graph 1 Graph 2 Graph 3 Graph 4
 Graph 5 Graph 7 Graph 8 Graph 9
 Graph 10 Graph 11 Graph 13 Graph 14
 Graph 15 Graph 16 Graph 17 Graph 19
 Graph 20 Graph 21 Graph 22 Graph 23

Quit
 Next page
 Previous page
 + 5 page
 - 5 page
 Scale up
 Scale down
 Option menu
 Graph menu
 Mode selection
 EPS output

* Number of graphs
 Covariant : 28
 Unitary : 24
 Selected : 0
 * mode :
 Draw Unitary
 1-th out of 24
 * EPS-out : 0 files

GRACEFIG : Coded by S.Kawabata, Mimasitotaya, KEK, JAPAN

- * kinematical setup
- * MSSM parameters
- * polarization and graph selection

gauge invariance check (R_{\square})

ans1	=	0.139175455829902	covariant gauge
ans2	=	0.139175455829902	unitary gauge
ans1/ans2 - 1 = -2.220446049250313E-016			

We have checked the gauge invariance with quadruple-precision

SUSY processes with up to 6 external particles

582,102 processes

||

DONE

Integration

Convergency Behavior for the Integration Step

```
-----  
<- Result of each iteration -> <- Cumulative Result -> < CPU time >  
IT Eff R_Neg Estimate Acc % Estimate(+ Error )order Acc % ( H: M: Sec )  
-----  
 1  92  0.00  1.145E-01  0.514  1.145249(+0.005883)E-01  0.514  0: 0:37.68  
 2  92  0.00  1.154E-01  0.549  1.149243(+0.004311)E-01  0.375  0: 0:44.35  
 3  91  0.00  1.143E-01  0.515  1.147059(+0.003478)E-01  0.303  0: 0:51.01  
 4  91  0.00  1.137E-01  0.504  1.144273(+0.002972)E-01  0.260  0: 0:57.66  
 5  91  0.00  1.135E-01  0.485  1.142069(+0.002615)E-01  0.229  0: 1: 4.33  
-----
```

***** END OF BASES *****

<< Computing Time Information >>

```
(1) For BASES          H: M: Sec  
    Overhead           : 0: 0: 0.00  
    Grid Optim. Step   : 0: 0:31.00  
    Integration Step    : 0: 0:33.33  
    Go time for all     : 0: 1: 4.33
```

```
(2) Expected event generation time  
    Expected time for 1000 events : 1.16 Sec
```

3. 1-loop level system

Renormalization scheme

gauge symmetric, on shell scheme

by M. Kuroda

SM part : conventional approach

cf. Bohm, Hollik and Spiesberger, Fortschr. Phys. C34 (1986) 687

Higgs, Chargino and Neutralino sector : Dabelstein's approach

cf. Dabelstein, Z. Phys. C67 (1995) 495

(wavefunction ren. const. ; only to the unmixed bare states)

Sfermion sector : Kyoto approach

cf. Aoki et al., Prog. Theor. Phys. Suppl. 73 (1982) 1

(wavefunction ren. const. ; only to the mixed mass eigenstates)

Note GRACE/SM 1-loop : Kyoto approach

How to use?

almost the same to Tree-level GRACE/SUSY!

Examples ; $e^- e^+ \rightarrow \tilde{\chi}_1^+ \tilde{\chi}_1^-$

```
Model="mssm2206ct.mdl";
Process;
  ELWK={4,2};
  QCD=0;
  Initial  ={electron positron};
  Final    ={chargino1 anti-chargino1};
  Kinem="2001";
  Expand=Yes;
  Block=No;
  AnyCT=Yes;
  Extself=Yes;
Pend;
```

Refs.

M. A. Diaz, S. F. King and A. Ross,
Nucl. Phys. B529 (1998) 23, hep-ph/0008117

T. Blank and W. Hollik, hep-ph/0011092

* Full Electroweak correction ;
1908 x 7 diagrams

Input parameters

$$m_{\tilde{t}_1^+} = 150 \text{ GeV}$$

$$m_{\tilde{t}_2^+} = 420 \text{ GeV}$$

$$m_{\tilde{h}^0} = 75 \text{ GeV}$$

$$\tan \beta = 5$$

$$A_f = M_F = 500 \text{ GeV}$$

$$m_{\tilde{\chi}} = 500 \text{ GeV}$$

$$m_{A^0} = 150 \text{ GeV}$$

Internal checks

$$\sqrt{s} = 500 \text{ GeV}$$

@ C_{UV} dependence

tree + 1 loop + soft photon

$$0.049811286 \text{ (pb)} \quad C_{UV} = 0$$

$$0.049811273 \text{ (pb)} \quad C_{UV} = 100$$

@ photon mass \tilde{m} dependence

tree + 1 loop + soft photon

$$0.049811286 \text{ (pb)} \quad \tilde{m} = 10^{21} \text{ GeV}$$

$$0.049809483 \text{ (pb)} \quad \tilde{m} = 10^{19} \text{ GeV}$$

@ critical photon energy k_c dependence

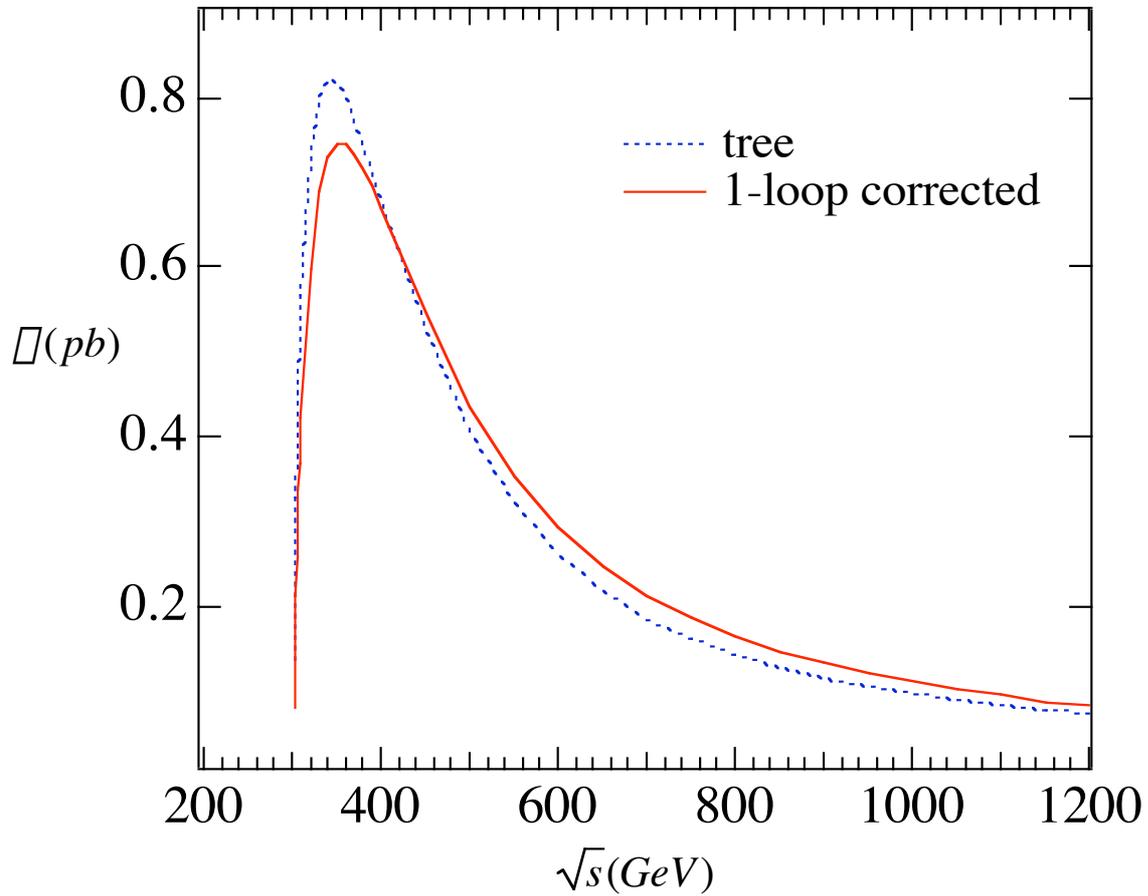
tree + 1 loop + soft photon + hard photon*

$$0.434817368 \text{ (pb)} \quad k_c = 0.1 \text{ GeV}$$

$$0.434977143 \text{ (pb)} \quad k_c = 0.001 \text{ GeV}$$

* hard photon process $e^- e^+ \rightarrow \tilde{\chi}_1^+ \tilde{\chi}_1^0$
: by GRACE/SUSY tree level system

$$e^- e^+ \rightarrow \tilde{\chi}_1^+ \tilde{\chi}_1^0$$



$$m_{\tilde{\chi}_1^+} = 150 \text{ GeV}$$

$$m_{\tilde{\chi}_2^+} = 420 \text{ GeV}$$

$$m_{\tilde{\chi}_1^0} = 75 \text{ GeV}$$

$$\tan \beta = 5$$

$$A_f = M_F = 500 \text{ GeV}$$

$$m_{\tilde{g}} = 500 \text{ GeV}$$

$$m_{A^0} = 150 \text{ GeV}$$

Preliminary

4. Outlook

@ more checks

Non-linear gauge in MSSM

$$F_{W^\pm} = (\partial_\mu \pm ie\tilde{\alpha}A_\mu \pm igc_w\tilde{\alpha}Z_\mu)W^{\pm\mu} \\ \pm i\tilde{\alpha}_W \frac{g}{2} (v + \tilde{\alpha}_H H^0 + \tilde{\alpha}_h h^0 \pm i\tilde{\alpha}G^0)G^\pm$$

$$F_Z = \partial_\mu Z^\mu + \tilde{\alpha}_Z \frac{g_Z}{2} (v + \tilde{\alpha}_H H^0 + \tilde{\alpha}_h h^0)G^0$$

$$F_\mu = \partial_\mu A^\mu$$

@ more processes

decays, final 2-bodies, 3-bodies, ...

$$e^- e^+ \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^0$$

25126 x 22 diagrams !